Coffee Powder Reused as a Composite Material

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***Abstract*—This project was set within the discipline of Industrial Design from the Masters in Industrial and Product Design first year of the Faculties of Engineering and Fine Arts of the University of Porto. The main objective was the creation of one or more objects from the reuse of wasted materials in the municipality of Matosinhos, in Porto, Portugal. It was also necessary to take into account the low cost of creations in an attempt to generate profit for the poorest communities in the region.**

Based on data provided by the International Coffee Organization, it is estimated that its overall consumption in 2014 was 149.8 million bags of 60 kg [5]. In the case of Portugal, in the same year, were consumed 823,000 which represent a per capita consumption of around 4.7 kg [6]. According to the same source, the annual coffee demand from 2011 to 2014 increased by 2.4%. It is noted further that this increase is gradual, being registered every year. It is therefore plausible to deduce that this tendency will continue in the near future.

This theme has emerged as a way to fight this problem through design. The research developed aims to present a production method for reuse ground coffee leftovers. The main goal to be achieved is to obtain a moldable material, composed by coffee grounds and a suitable binder found through testing and research. It is also intended that the material created is durable and washable, with prospects of extending the realities in which it can be used.

Through a Designer's point of view, the composite material developed within this mixture can be used in a variety of products, from simple coffee table tops to light emitting objects with original effects, the options are vast and abundant.

This work presents the results of tests done with the different mixtures seeking to obtain the desired material. As long as the mixture is moldable almost every imaginable object can be produced by casting it in a mold produced in different materials.

Keywords— Coffee grounds, waste, reuse, design, additive manufacturing.

I. INTRODUCTION

This article aims to present the different strategies that are currently being adopted in the coffee reuse industries. The relevance of this study is justified by the coffee sui generis characteristics, such as odor, visual appearance and texture, as well as the abundance of raw materials, most of which are normally discarded after serving their primary function. The results presented here in terms of tests will translate the different mixtures used in order to obtain the intended material.

II. COFFEE REUSE STRATEGIES

There are already reuse strategies in several areas, from agriculture to fuel. "The coffee grounds material has been consolidating itself as one of the most abundant biological resources of the world for use as green energy" [2]. However, in the Design area there are also ways of creating products with coffee grounds based materials beginning to be explored. The solutions that have been tested in this area are divided by the features presented by the final material, as a result of different mixtures between coffee grounds and other binding materials.

An example is Kaffeeform. "Kaffeeform is a recycled innovative material created with coffee grounds, vegetable fibres, cellulose and biopolymers. After five years of experimentation and research, an original formula was created to transform old coffee in new products." [4].

AgriDust is a design created by the Italian Product Designer Marina Ceccolini, which consists of using some food residue such as coffee grounds, peanut or orange peels mixed with a binder of potato starch base. "AgriDust can be used to create packaging, plant pots and, in addition, using cold technology lends itself as a material for 3D printers, in which the classical extruder is replaced by a syringe" [1].

Another example of coffee use in creating raw material with 3D printing capabilities is the Hoop by Francesco Pacelli. "Francesco Pacelli, a member of + Lab at the Polytechnic University of Milan, frightened by the exponential amounts of food waste from the present to 2050, had an interest in ways to recycle waste in a sustainable manner, combining it with an ancient material, clay" [3]. The Hoop design by Francesco Pacelli has many similarities to the AgriDust by Marina Ceccolini, although the mixture added to coffee is completely different. In this particular case the mixture reached seeks a higher consistency. This material is also molded and has the ability to be extruded with the aid of a syringe.

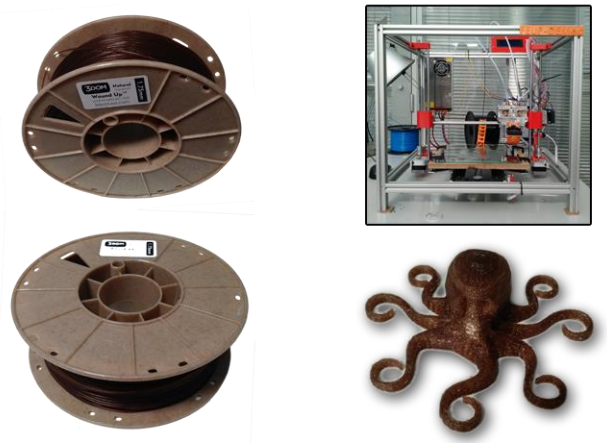

Fig. 1. Woun-up by 3Dom [7].

"Wound Up™ is a 3D printing filament created using coffee waste by-products" [7]. This material produced by the American company 3Dom uses coffee residues mixed with PLA (polylactic acid) to create a 3D printing material with visibly unique printing finishes. The filament produces a brownish colour and a natural noticeable grain (Fig. 1). This is the first of a line of 3Dom USA intriguing materials called composite c2renew. More bio-based products will be launched in the near future. One of the strongest features of this product is the ability to be printed on any machine capable of printing with PLA.

III. EXPERIMENTATION

The experimental work appears as a way to establish the main and most suitable material to add to coffee, in creating this material.

The first binder to be tested was Biresin CR83, an epoxy resin with 30% catalyst and the ratios between this material and the coffee have varied, in an attempt to understand what types of results could be obtained.

Then starch (potato and corn) was tested, because it is a natural and biodegradable polymer. Several formulas of this material were tested and the cures were made at different temperatures and for various lengths of time.

Later, experiments were performed with pine resin, as it is a Portuguese material, and is readily available. Also in this case, the ratios varied and the cure was virtually instantaneous.

Because pine resin showed very weak results, it was decided to add other materials to the mix in an attempt to give greater strength to the final material. Therefore wax was selected, but the results were still unsatisfactory.

Finally, experiments were done using Polylactide (PLA) as a binder and positive results began to appear. PLA is a biodegradable thermoplastic derived from natural lactic acid from corn, maize or milk. Is a thermoplastic derived primarily from annually renewable resources (maize, corn or milk), and it is available in a number of grades, designed for ease of processing. In-line drying may be needed to reduce water content for extrusion and molding. The recommended molding temperature is between 165C and 170C.

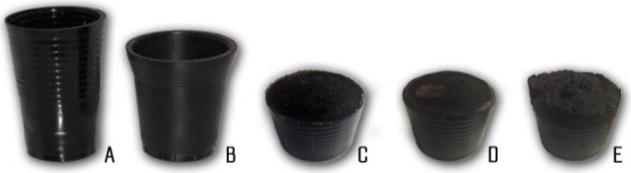

Fig. 2. Coffee cups produced with epoxy resin mixtures.

It resembles clear polystyrene, provides good aesthetics (gloss and clarity), but it is stiff and brittle and needs modification using plasticizers for most practical applications. It can be processed like most thermoplastics into fibres, films, thermoformed or injection molded.

PLA is transparent and has FDA approval for food packaging. PLA film and sheet can be printed and laminated. Biopolymers are, however, expensive, costing 2 to 6 times as much as commodity plastics like polypropylene.

Food packaging, plastic bags, plant pots, diapers, bottles, cold drink cups, sheet and film are some examples of the typical applications of this material (CES EDUPACK 2016, Granta Design, UK).

This information legitimates the use of this material in the project, having into account its features with regard to food contact.

IV. RESULTS AND DISCUSSION

In the first attempt for combinations between coffee and a binding material, the choice was an epoxy resin. Fig. 2 presents the results obtained with this mixture, using different ratios coffee/resin.

The epoxy resin used was Biresin CR83 produced by the German company SIKA, with 30% catalyst and the curing time was, as usual, 24 hours at room temperature. As a mold, simple plastic coffee cups available at any coffee vending machine were used.

Cups A and B represent tests performed to symbolize the existing coffee cups on the market. In object C the ratio used was a coffee part to four parts resin, while in object D the ratio was 1:2 and in E 1:1.

These experiments were performed to demonstrate the possibility of mixture between coffee remains and a binder, but have never been seen as a possibility in this project, because the used resin is not safe for food contact.

The next step was the use of starch. Being a natural, biodegradable substance, both potato and corn starches were taken into consideration for this study as potential solution.

The way to materialize this experiment involves mixing the starch with cold water to dissolve it. Then there is the mixture with a certain percentage of coffee and the product obtained was placed in an oven, using different temperatures and time to reach the best properties.

Fig. 3. Samples of coffee-PLA mixtures. The samples presented here represent the experimental mixture between PLA and coffee powder.

However, this experiment has proven to be unsuccessful, since all the results have shown, after some time, moisture signals itself through the appearance mold.

At a later stage it was decided to test pine resin as a binder to ascertain whether its characteristics could give a reasonable material when mixed with coffee. It was quickly realized that this union would be fruitless, given the fragility of the resin itself as most results have become brittle and not very rigid.

After a few tests with negative results, the option was to use the same pine resin, but with wax addition in an attempt to improve its physical characteristics. Very interesting visual results were produced, but the problem of resistance remained and the resulting material was still very brittle, thus this possibility was discarded.

Finally, and after several experiments, the material chosen for the mixture with coffee was PLA. There are several reasons for choosing this material, although the main reason is the perfect symbiosis with the coffee in the design of a perfectly moldable and inert material in contact with food.

Fig. 3 represents some of the first experiments with PLA in conjunction with coffee residue. The percentages were not taken into account, but it was quickly realized it would work for the fulfilment of the pre-defined goal.

After realizing that this would be the ideal material, an exemplificative 3D CAD model was made in Solidworks and the file was subsequently saved in STL format. From there, a 3D printed piece was created and from that a mold was made out of silicon. For the creation of this mold, the silicone used was 950 VTX, provided by SLM and the catalyst proportion was 10%. The curing time was 24 hours as usual with this type of resin. With the mold ready, various experiments took place with different percentages of both materials to understand what would be the most suitable mixture (Fig. 4).

It was concluded, therefore, that the greater the proportion of coffee in the blend, the longer would have to be the heating of the two materials in order for them to merge. 40% is the threshold amount for this mixture. Although it is possible to increase this amount, the excess time and the thickness of the final material do not justify it.

The object behaves according to the goal, some insulation, withstands the contact with the hot coffee and mechanical resistance, fulfilling its function perfectly.

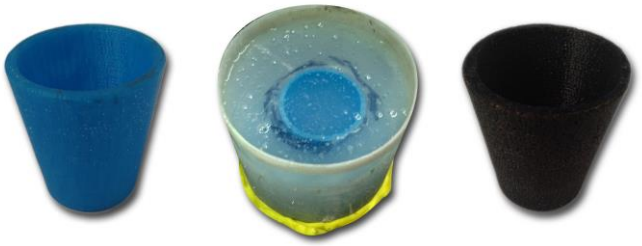

Fig. 4. 3D printed part in PLA (left), Silicone mould (centre) and casted part (right).

This mixture presents however a structural problem, since the part cannot be machine washed, due to the high temperatures to which it would be subjected. In this case, the material undergoes irreparable deformation and gets unusable. The piece has therefore to be washed by hand, preferably with cold water.

V. DESIGN PROPOSAL

From the point of view of design, the focus was to try to create an object from the developed formulation of coffee-PLA. In an attempt to generate a semantic cycle, it seems interesting that the primary object developed based on coffee waste is a cup of coffee (Fig. 5).

Taking into account the characteristics of the material created and that it is a moldable material, the shape of the idealized objects is only limited by the imagination and of course the costs of the mold itself.

The use for plant pots, since it is biodegradable and there are already a number of developments in this area using coffee as a fertilizer, presents interesting possibilities also.

VI. CONCLUSIONS

The developed material allows the coffee waste to be reused in the universe of Industrial and Product Design. There is still some way to go to improve this technology, but at this time one can already realize that coffee does not need to be just another piece of trash, it can be turned in to a building material, very efficient and applicable to a large number of areas.

From an experimentation point of view, there have been several tests with different binding materials. It began with epoxy resin, followed by starch, in a later stage pine resin and wax, but the material that showed the best results, for the time being was PLA.

Nevertheless, the material has limitations, and cannot be used at high temperatures (washing machine). It can therefore be concluded that that there is still some way to improvement to create an ideal material, but the forecasts are quite positive.

Taking into account that it is a moldable material, the creation of objects is only limited by the imagination.

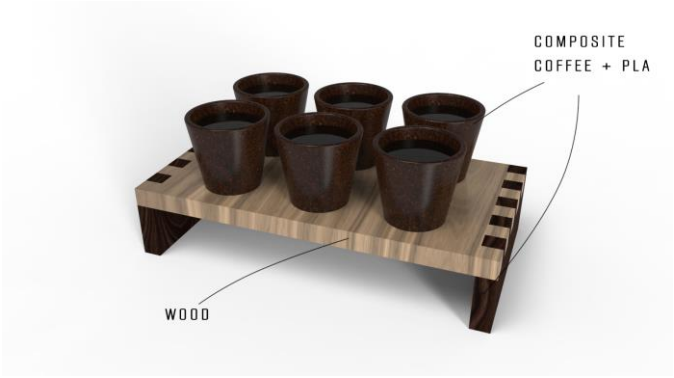

Fig. 5. Tray for coffee cups.

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